

Electric Tachyon Inflation

Daniel Cremades*

Department of Applied Mathematics and Theoretical Physics. Wilberforce Road, Cambridge, CB3 0WA.
United Kingdom

We propose that under certain conditions the universal open string tachyon can drive topological inflation in moduli stabilised frameworks. Namely, the presence of electric field in the world volume of the D-brane can slow down its decay leading to a phenomenological model of inflation. The conditions for inflation to take place are difficult to satisfy in the standard warped deformed conifold but easier to realise in other geometries.

1 The Problem of Inflation in String Theory

Inflation has become, throughout the years, in the standard paradigm of modern cosmology. In spite of its several drawbacks, mainly associated to the absence of a fundamental theory giving support to the paradigm, its phenomenological success and the simplicity of the ideas involved in its solution of the flatness and homogeneity problems have elevated inflation to the status of unique (effective) description of the physics of the primordial universe. It is then desirable to embed this phenomenologically successful paradigm into a robust and fundamental theoretical framework. String theory is believed to be an example of such framework.

The embedding of inflation in string theory has to face one obvious difficulty. Inflationary models are generically characterised by scalar fields with very flat potentials. Whereas string constructions have, upon compactification, lots of scalar fields (moduli), generically they exhibit steep runaway potentials. It is necessary then to have some moduli stabilisation mechanism at work to prevent undesirable effects to happen like decompactification of the internal manifold instead of inflation.

A second difficulty for inflation in string theory is the standard η -problem of N=1 supergravity models, that was revisited in [1]. Generic mechanisms for moduli stabilisation involve the generation of non-trivial superpotentials by some combination of fluxes. If the inflaton field happens to belong to some chiral multiplet of the underlying N=1 supergravity, additional contributions to the scalar potential might appear yielding generically large contributions to the mass of the inflaton that halt inflation. An obvious way to overcome this difficulty is the consideration of some source of inflation that is explicitly non-supersymmetric and thus unrelated to the underlying N=1 structure of the theory. Non-BPS branes are an example of such explicitly non-supersymmetric system whose decay is able to produce inflation. This work is devoted to the study of the conditions under which the decay of non-BPS produces inflation in generic Type II configurations.

2 Non-BPS D-branes and their effective action

Apart from standard BPS D-branes, Type II string theory has a number of non-BPS objects in its spectrum named non-BPS D-branes. A non-BPS D_p-brane is a p+1-dimensional (p odd (even) for Type IIA(B)) hypersurface in which open strings can end. The lowest lying spectrum of such objects contains a real tachyonic mode that signals the instability of the object towards decay. A closely related system is that of

* E-mail: d.cremades@damtp.cam.ac.uk

the bound state made by a Dp-anti-Dp pair on top of each other. In this case, the tachyonic mode living in the world volume can be described by a complex field.

The dynamics of the tachyon field $T(x)$ in both cases are codified in the following low energy theory effective action [2, 3]

$$S = -T_p \int d^{p+1}x V(T) \sqrt{g_{\mu\nu} + D_\mu T D_\nu T + (F_{\mu\nu} + B_{\mu\nu})} + \int dT \wedge W(T) e^{F+B} \wedge C \quad (1)$$

where T_p is the tension of object, to be specified below; D stands for the covariant derivative with respect to the corresponding gauge field living in the world-volume of the brane¹, whose field strength is given by $F_{\mu\nu}$; $g_{\mu\nu}$ and $B_{\mu\nu}$ are the pullbacks of the metric and B-field in the worldvolume of the brane and C is the standard formal sum of RR potentials that appear in the CS terms. $V(T)$ is the tachyon potential and $W(T)$ is a function whose asymptotic behaviour is known but whose form will not be relevant in what follows. The tachyon potential is given by [5]

$$V(T) = \frac{1}{\cosh(\frac{T}{\sqrt{2\alpha'}})}. \quad (2)$$

In spite of the subtleties required to interpret (1) as an effective action, it seems to capture some non-trivial features of the decay of the D-brane. In particular, it leads to the correct energy-momentum tensor as computed by CFT methods (see [6] for a review). Since this is the coupling of the system to the gravitational field, the action (1) is the correct tool we must use to describe tachyon decay in cosmological settings, where we are mostly interested in the classical coupling between the source of inflation and the gravitational field, rather than in details concerning the quantum behaviour of the system at the microscopic level

Even considering the action (1) together with the potential at a purely classical level, some peculiarities arise. First of all, the tachyon condenses at $T \rightarrow \infty$ where $\dot{T} \rightarrow 1$. Secondly, at $T \rightarrow \infty$ the action vanishes. This is in accordance with the fact that the non-BPS D-brane should decay to something topologically identical to the closed string vacuum, with no open string degrees of freedom present. One can compute the density and pressure of the system when $T \rightarrow \infty$ finding

$$p = M_{pl}^4 \frac{V(T)}{\sqrt{1 - \dot{T}^2}} \rightarrow \text{const.}, \quad p = -M_{pl}^4 V(T) \sqrt{1 - \dot{T}^2} \rightarrow 0. \quad (3)$$

This pressureless fluid is conventionally called *tachyon matter* [4], and it was given in [5] the microscopic description of a coherent state of highly excited closed string modes ($m \sim 1/g_s$) localised near the original position of the non-BPS branes. They found that the ratio of the pressure of the system with respect to its energy density was of order g_s , and thus in the classical limit both descriptions match.

In [7] was proposed that both descriptions do not only hold at the classical (tree) level but one can make a complete correspondence even at the quantum level. The proposal (called the *completeness conjecture*) states that in principle one can formulate an open string field theory describing the decay of the D-brane just in terms of open strings, and no explicit coupling to closed strings is needed in order to make it consistent. The conjecture thus states that one can describe the set of closed string fields arising from the decay and its interactions just in terms of open strings, and this description in terms of open strings is complete. Remarkably, this conjecture has been proven true in two dimensional string theory [7].

Finally, let us point out one final result that will be useful for our purposes. It was found in [8] that the decay of a non-BPS system is slowed down by a factor $\sqrt{1 - E^2}$ when electric field (or, analogously, a density of fundamental string charge) has been turned on in the world volume of the brane. This is fact will be most useful for our results in what follows.

¹ Note that in the case of the single non-BPS brane the tachyonic mode is uncharged.

3 Tachyon Inflation

3.1 Inflation basics

The proposal of tachyon inflation is to use the energy released by the D-brane decay to produce inflation[9, 10]. Our starting point is the four dimensional action

$$S = \int d^4x \sqrt{-\bar{g}} \left(\frac{M_{pl}^2}{2} R - \mathcal{A}V(T) \sqrt{1 + B\partial_\mu T \partial^\mu T} \right), \quad (4)$$

where \mathcal{A} and B are, respectively, dimension four and dimensionless parameters that come from the dimensional reduction of (1), as we will see. Let us assume a standard FRW ansatz² for the metric $d\bar{s}^2 = \bar{g}_{\mu\nu}dx^\mu dx^\nu$:

$$d\bar{s}^2 = -(dt)^2 + a(t)^2 \left(\frac{dr^2}{1 - kr^2} + r^2 d\theta^2 + \sin^2 \theta d\phi^2 \right). \quad (5)$$

The corresponding equations of motion are respectively the Friedmann (constraint) equation, the evolution equation for the scale factor $a(t)$ (recall that $H \equiv \dot{a}/a$) and the equation of motion for the tachyon field:

$$H^2 = \frac{1}{6} \frac{A \cdot V(T)}{\sqrt{1 - B\dot{T}^2}} - \frac{k}{a^2}, \quad (6)$$

$$\frac{\ddot{a}}{a} = \frac{A \cdot V(T)}{6\sqrt{1 - B\dot{T}^2}} \left(1 - \frac{3}{2}B\dot{T}^2 \right) \quad (7)$$

$$3H \frac{AVB\dot{T}}{\sqrt{1 - B\dot{T}^2}} + \partial_t \left(\frac{ABV\dot{T}}{\sqrt{1 - B\dot{T}^2}} \right) = -A\sqrt{1 - B\dot{T}^2} V'(T), \quad (8)$$

where $A \equiv 2\mathcal{A}/M_{pl}^2$. In order to solve this system of differential equations one needs a set of initial conditions of $a(t)$ and $T(t)$. We will choose time symmetric initial conditions in order to obtain the (classical description of the) kind of decay described in [9]: this implies $\dot{T}(0) = \dot{a}(0) = 0$. Automatically this implies $k = 1$ to satisfy Friedmann's equation and consequently $a(0) = (6/AV(T_0))^{1/2}$. The solution is then completely determined in terms of A , T_0 and B . A complete analysis of this system of equations³ has been performed in [11]. This analysis shows that the evolution of the system takes place mainly in the slow-roll regime; we will therefore assume these conditions from here on.

In order to connect with the standard inflationary terminology, we have to define a canonically normalised inflaton field in terms of the tachyon as

$$\phi = \sqrt{AB} \int \sqrt{V(T)} dT \quad (9)$$

As in standard inflation, we will assume that T is a spatially homogeneous, time dependent field. The slow-roll parameters measure the ability of some potential to produce inflation. The form of these parameters in terms of T is⁴

$$\epsilon = \frac{M_{pl}^2}{4\alpha'AB} \frac{\sinh^2 x}{\cosh x}, \quad \eta = -\frac{M_{pl}^2}{2\alpha'AB} \cosh x \left[1 - \frac{3}{2} \tanh^2 x \right], \quad (10)$$

² The obvious question is if such an ansatz is a solution of the supergravity equations of motion. In general this question is very difficult to answer since time-dependent backgrounds for string theory have always been problematic. Here we are taking an effective field theory approach, in which all the fields that are not relevant for the physics under consideration are assumed to be integrated out. For this to be consistent, the energies involved in the low energy theory have to be smaller than the typical scale associated to these higher dimensional modes, that is assumed to be the string scale.

³ This analysis also includes the coupling of the system to the volume modulus of the compactification manifold, under the assumption that its dynamics are governed by a KKLT-like potential, in order to examine how cosmological inflation can be compatible with moduli stabilisation.

⁴ Note that the functional form of the η parameter makes the system suitable for an η -problem if the coefficient of $\cosh x$ is of order one.

with $x \equiv \left(\frac{T}{\sqrt{2\alpha'}}\right)$, and both of them must be much smaller than one to yield a phenomenologically acceptable inflationary scenario. The number of e-folds in the slow roll approximation is then given by

$$N \simeq \frac{AB}{M_{pl}^2} \int_{T_e}^{T_b} \frac{V^2}{V'} dT = \frac{2\alpha' AB}{M_{pl}^2} \log \left[\coth \left(\frac{T_b}{\sqrt{8\alpha'}} \right) \right], \quad (11)$$

where ' means now derivative with respect to T , and T_b and $T_e = \infty$ are, respectively, the values of the tachyon field at the beginning and end of inflation. The amplitude of density perturbations is given by

$$\delta_H \simeq \frac{\sqrt{\mathcal{A}^2 B}}{5\pi\sqrt{3}M_{pl}^3} \frac{V^2}{V'} = \sqrt{\frac{\alpha' \mathcal{A}^2 B}{75\pi^2 M_{pl}^6}} \operatorname{csch} \left(\frac{T_b}{\sqrt{2\alpha'}} \right). \quad (12)$$

As it is well known, to match observational constraints it is necessary to have $N \geq 65$, $\delta_H \simeq 2 \times 10^{-5}$. This last numerical value is given by the COBE normalisation, which must be computed at the point when the last 60 e-folds of inflation start. Here we can already see what is the main phenomenological point of tachyon inflation. Assuming that generically we will have $\alpha'/M_{pl}^2 \leq 1$, if one manages to get a value of the adimensional quantities

$$\frac{\alpha' \mathcal{A}}{M_{pl}^2} B \gg 1, \quad \left(\frac{\alpha' \mathcal{A}}{M_{pl}^2} \right)^2 B \ll 1, \quad (13)$$

then generically we will have phenomenologically successful inflation, what basically amounts for a small value of $\alpha' \mathcal{A}/M_{pl}^2$ and a large value of B .

3.2 Compactification of the tachyon action

Let us see now what is the origin of these parameters \mathcal{A} and B that appeared in the four dimensional effective action (1). Consider a $p+1$ -dimensional non-BPS system in Type II theory⁵, wrapping the whole four dimensional space-time and some $p-3$ -cycle in the internal space. This system will be described by the tachyon action (1). Consider the embedding of this action on a metric of the form

$$ds_{10}^2 = e^{2\omega(y)} \bar{g}_{\mu\nu} dx^\mu dx^\nu + \tilde{g}_{mn} dy^m dy^n \quad (14)$$

and its dimensional reduction down to four dimensions. The six-dimensional metric \tilde{g} has the generalised Calabi-Yau form that is found in generic flux compactifications, and whose moduli are supposed⁶ to be stabilised⁷. The reduction down to four dimensions can in principle be very complicated but we can make some simplifying assumptions. First, we will assume that the warping factor $\omega(y)$ is constant along the directions of the brane. Secondly, we will suppose that the pullback of the B -field and the gauge field are zero in the world-volume of the brane (we will relax this condition later). Under these assumptions, the four dimensional action takes the form (4) with⁸

$$\mathcal{A} = e^{4\omega} T_p V_{p-3}, \quad B = e^{-2\omega}, \quad (15)$$

⁵ We prefer to maintain the discussion generic at this point. In Type IIA(B), the object is a single non-BPS brane for p odd (even) and a pair Dp -anti- Dp for p even (odd).

⁶ An explicit study of inflation in moduli stabilised frameworks requires knowledge of the explicit stabilisation mechanism. It was performed in [11] a complete analysis of tachyon inflation in the presence of moduli stabilisation for a particular IIB model with a single Kahler modulus, subject to a KKLT-like potential. We assume that other moduli stabilisation mechanisms can be analysed and compatibilised with tachyon inflation in a similar way.

⁷ As emphasised in section 1, this can turn out to be a non trivial constraint. Even if in our case the tachyon field will not belong to any kind of chiral multiplet and thus in principle its dynamics will not be (directly) influenced by the particular mechanism of moduli stabilisation taking place, as it was the case in [1], generic moduli potentials can put non trivial upper bounds on the value of the dimensionful parameter \mathcal{A} in order to prevent undesirable effects in cosmological settings like decompactification of the internal dimensions.

⁸ In the absence of internal magnetic field, the lowest tachyonic mode has a constant profile over the internal dimensions and thus the CS term will not contribute to the effective four dimensional action.

with

$$V_{p-3} = \int d^{p-3}y \sqrt{P[\tilde{g}]_{ab}}, \quad T_p = \sqrt{2} \frac{(2\pi)^{-p} \alpha'^{-\frac{p+1}{2}}}{g_s}, \quad (16)$$

where $P[\tilde{g}]$ is the pullback of the internal metric in the world volume of the brane. Note that the tension of the p -brane gets an extra $\sqrt{2}$ factor in the case of the brane-antibrane pair.

The scales involved in the problem are as follows. The Planck mass is given by

$$\frac{M_{pl}^2}{2} = \frac{(2\pi)^{-7}}{g_s^2 \alpha'^4} \int d^6y \sqrt{\tilde{g}} e^{2\omega}. \quad (17)$$

The (closed) string scale is not known since in general it is not possible to quantise the string in arbitrary backgrounds. However, we can estimate it as some numerical value c that is given e.g. by the fluxes in the configuration times α' . The (open) string scale in a warped compactification will depend in the point in the internal manifold where the subset of open strings under consideration is attached. In our case it will be set by the mass of the tachyon and thus will be given by $m_s^2 \sim \frac{c}{B\alpha'}$. As we will see, under the circumstances of interest for our problem we will be able to set $c = 1$. The Hubble scale is the typical energy scale during inflation and is given by $H^2 = \mathcal{A}V/(3M_{pl}^2)$. For our approximation to make sense, then, the Hubble scale must be smaller than the string scale at all times. But this seems to lead to a contradiction, since comparison with (10) and (11) implies that either N is small or η is of order 1. There are two possible ways to overcome this difficulty. First, to assume that c has a value somewhat bigger than one. Note that for $c \sim O(10)$ the string scale would be twice as large as the Hubble scale. Secondly, the addition of electric field in the world-volume of the brane will lower the Hubble scale keeping the string scale fixed. Let us review how the addition of world-volume electric field will generically help in obtaining phenomenologically successful tachyon inflation.

3.3 Addition of electric field

As advanced, it is known that the addition of electric field in the world volume of a non-BPS D-brane can slow down its decay. We want to make use of this fact to generate long-lasting inflation, and we will see that the consideration of this degree of freedom is also convenient for other phenomenological purposes. To turn on electric field along one compact direction in the world volume of the D-brane it is necessary for the cycle wrapped by the D-brane to possess non-trivial one cycles⁹. We will generate this electric field by turning on a world-volume gauge potential that has (locally) the form $A = -Exdt$, where x is the coordinate that parametrises the 1-cycle. This vector potential cannot be transformed into a time-dependent Wilson line because of the topology of the space and thus the presence of this constant electric field is consistent with the symmetries of the system and the cosmological evolution, provided it satisfies the Maxwell equation

$$\partial_x \frac{\sqrt{-\tilde{g}} \mathcal{A}V(T)E}{\sqrt{1 - B\dot{T}^2 - E^2}} = 0. \quad (18)$$

This tells us that if \tilde{g} , \mathcal{A} and B are independent of the internal coordinate x then a constant E will satisfy this equation. This is true for example when the $p-3$ cycle wrapped by the D-brane is a torus. In this case the 4-d effective Lagrangian can be rewritten as

$$\hat{A}V(T)\sqrt{-\tilde{g}}\sqrt{1 - B\dot{T}^2}, \quad (19)$$

where $\hat{A} = A\sqrt{1 - E^2}$ and $\hat{B} = B/(1 - E^2)$. Thus the total number of e-folds, which is proportional to AB , would increase by a factor $1/\sqrt{1 - E^2}$, whereas the density perturbations will remain constant¹⁰.

⁹ Note that one can consider one-cycles that are trivial on a Calabi-Yau but non-trivial when restricted to some higher dimensional p -cycle, $p < 6$.

¹⁰ Pushing the value of E to be close to 1 should not be considered as fine-tuning, since the relevant physical variable is not E but the electric charge $q \sim E/\sqrt{1 - E^2}$ [12]. Putting E close to 1 is just equivalent to increasing q .

Note that the addition of electric field will also help in the problem with the scales mentioned in the previous section, since it will lower the Hubble scale keeping constant the string scale (which is unaffected by the presence of electric field). Also, the electric field induces in general fundamental string charge in the world volume of the brane [12], and thus these fundamental strings will be left over as a remnant of the tachyon condensation. Note, however, that in a manifold without one cycles like a CY these fundamental strings will generically contract to zero size and annihilate into the vacuum, so that the presence of F-cosmic strings is not expected in these situations.

In order to illustrate how the presence of electric field can help obtaining phenomenological numbers for inflation, let us consider the sample values for the parameters (in units in which $M_{pl}^2 = 1$) $A = 10^{-6}$, $B = 5 \cdot 10^9$, $T_b = 0.1$, $\alpha' = 10^{-3}$. Then the number of e-folds is $N = 1.07$ and the density perturbations are given by $\delta_H = 1.2 \cdot 10^{-5}$. Turning on 60 units of electric field ($E/\sqrt{1 - E^2} = 60$) one gets $N = 64.38$ and δ_H remains unaltered. With respect to the scales, one has $m_s^2 = 2 \cdot 10^{-7}$ and $H^2 = 6 \cdot 10^{-10}$, in units where $M_{pl}^2 = 1$. This kind of estimations are confirmed by the full numerical analysis, see [11] for details.

3.4 Topological inflation

The fact that the tachyon potential (for the case of the non-BPS brane) has a \mathbf{Z}_2 symmetry $T \rightarrow -T$ might lead to the concern that the generic presence of domain wall defects upon tachyon condensation in this kind of potentials could make the model completely incompatible with observational constraints. This is not the case. Actually, this model is a concrete realisation of topological inflation in string theory.

Topological inflation was introduced in [13] partly as a way to ameliorate the issue of initial conditions of standard inflationary models. In topological inflation the initial conditions are governed by the existence of a topological defect at the maximum of a potential with degenerate minima. If the defect is thicker than the Hubble size H^{-1} , then a patch within the defect can inflate in all directions (including the ones transverse to the defect) and become our universe. The conditions for the thickness of the defect happen to be satisfied if the slow-roll condition, requiring η to be small, holds. This is easy to see since the thickness of the defect (δ) is inversely proportional to the curvature of the potential at the maximum which itself is proportional to η . Then, the condition $\delta \gg H^{-1}$ is satisfied if $\eta \ll 1$.

4 Explicit Examples

The search for explicit examples is the search for appropriate compactification manifolds.

4.1 Toroidal compactification

Even if this is a phenomenologically not very interesting case, since generically toroidal models have the string scale very close to the Planck scale, the torus is still interesting since it allows to appreciate most of the features of the problem. Consider the non-BPS p -brane wrapping $p - 3$ of the radial coordinates of the torus. Evaluation of this trivial case yields automatically

$$\mathcal{A} = \frac{\sqrt{2}(2\pi)^{-p}\alpha'^{-2}V_l}{g_s}, \quad B = 1, \quad \frac{M_{pl}^2}{2} = \frac{V}{(2\pi)^7 g_s^2 \alpha'}, \quad (20)$$

times a $\sqrt{2}$ factor in the case of brane-antibrane pairs, where V_l is the volume of the directions wrapped by the brane and V the volume of the torus, both in α' units. The number of e-folds and density perturbations are given by

$$N = \frac{(2\pi)^{7-p}g_s}{\sqrt{2}V_t}, \quad (21)$$

$$\delta_H^2 = \frac{(2\pi)^{21-2p}g_s^4}{75\pi^2 V_l V_t^2}, \quad (22)$$

with V_t the transverse volume to the brane in α' units. One can see that phenomenological numbers can be obtained e.g. setting $g_s \sim 0.1$, $V_t \sim 1$, $V_l \sim 10^{10}$, although obviously the addition of electric field can make the situation better. What this simple model shows us is that (in the absence of electric field) large volumes transverse to the brane seem to render tachyon inflation useless, at least as the main source of inflation.

4.2 Warped Deformed Conifold

The warped deformed conifold is one of the most celebrated geometrical constructions in (IIB) string theory since it provides an example of a throat created by the backreaction of fluxes in which the metric is explicitly known [14]. Though the metric is known, two limits are specially relevant for our purposes. The apex of the throat has the topology of a S^3 , and the metric is given by

$$ds_7^2 = e^{2\omega} d\bar{s}_4^2 + \tilde{R}^2 ds_{S^3}^2, \quad (23)$$

with $\omega = -2\pi K/(3g_s M)$ and $\tilde{R}^2 = g_s M \alpha'$. Far from the apex the geometry looks like $AdS^5 \times T^{1,1}$:

$$ds_{10}^2 = \frac{r^2}{R^2} d\bar{s}_4^2 + \frac{R^2}{r^2} (dr^2 + r^2 ds_{T^{1,1}}^2) \quad (24)$$

with $R^4 = \frac{27}{4}\pi g_s M K \alpha'^2$. Let us consider the decay of a non-BPS D6 brane wrapped in the S^3 in the apex of the deformed conifold. The computation of \mathcal{A} and B yields

$$\mathcal{A} = e^{-\frac{8\pi K}{3g_s M}} \frac{\sqrt{2}}{16\pi^3} g_s^{1/2} M^{3/2}, \quad B = e^{\frac{4\pi K}{3g_s M}}, \quad (25)$$

where M and K are the RR and NSNS flux density along the 3-sphere and its dual cycle, respectively. The Planck mass is given in this case by

$$\frac{M_{pl}^2}{2} = \frac{V_6}{(2\pi)^7 g_s^2 \alpha'^7}, \quad V_6 = k \left(\frac{2\pi}{3}\right)^3 \left(\frac{27\pi}{4} g_s M K\right)^{3/2}, \quad (26)$$

where $k \geq 1$ is some number. The number of e-folds is given by

$$N \simeq \frac{2\alpha' \mathcal{A} B}{M_{pl}^2} = \frac{27}{2} \left(\frac{4}{27\pi}\right)^{3/2} \frac{g_s e^{-\frac{4\pi K}{3g_s M}}}{k K^{3/2}} \simeq \frac{10^{-2} e^{-\frac{4\pi K}{3g_s M}}}{k K^{3/2}}, \quad (27)$$

that is a number at most of order 10^{-2} . Note that one cannot ameliorate this result by the addition of electric field since there are no 1-cycles in a S^3 . This result teaches us that in general warped configurations will not help in obtaining realistic models of inflation, and also that in general one is more likely to obtain (in the absence of electric field) phenomenological inflation in situations where the string scale is close to the Planck scale.

4.3 Other possible constructions

Addition of electric field generically allows for a phenomenologically viable model of inflation provided that the submanifold Σ wrapped by the non-BPS brane (or D-brane-anti-D-brane pairs) has $b_1(\Sigma) > 0$. One example of such manifolds are special Lagrangian manifolds. Explicit examples of SLAGs with $b_1(\Sigma) > 0$ were provided in [15]. An explicit computation of the number of e-folds and density perturbations needs the precise knowledge of the metric, but we have seen that these constraints are met with large enough value of the electric charge.

Other kind of constructions in which moduli are stabilised but allow at the same time for non-trivial one cycles are those involving twisted tori¹¹. In the particular construction considered in [16], the precise

¹¹ See [16] and references therein.

computation of the number of e-folds and density perturbations would be very similar to that of the toroidal case considered in section 4.1.

There are other effects that can ameliorate the phenomenological potential of the model like the addition of magnetic fields in the world volume of the brane. The presence of magnetic fields will generically improve the number of e-folds in a given configuration, but they will also complicate the dimensional reduction of the tachyon action. In principle they will generate non-trivial profiles for the tachyon wave function in the internal dimensions, as well as increase the number of four-dimensional tachyon fields. A complete investigation of magnetic tachyon inflation is thus beyond the scope of this work.

5 Conclusions

Tachyon inflation provides an example of topological inflation within the framework of string theory. The fact that the tachyon is a generic object in string theory and the fact that its presence is always linked to explicitly non-supersymmetric systems (and therefore free from the problems pointed out in [1]) makes it specially attractive for considering it as a source for inflation. We have considered here the conditions under which this kind of inflation can take place, from an effective field theory point of view. We have found two main results: that the systems in which it can work (in the absence of electric field) are those in which the string scale is very close to the Planck scale, and that the presence of electric field in the world-volume of the brane (or brane-antibrane pairs) that support the tachyon field can greatly improve the phenomenological potential of the model.

The end point of the decay is the least understood from a theoretical point of view, since most of the classical expectations fail when reaching this point [17]. A complete understanding of this regime will be crucial to address several other interesting questions regarding this model like reheating after inflation (that could take place along the lines suggested in [18]) or the possible over-closure of the universe due to tachyon matter pointed out in [19], based in arguments extrapolated from the classical description of the decay. We leave these questions for future work.

Acknowledgements I thank Fernando Quevedo and Aninda Sinha for the collaboration in the original paper and enlightening conversations and Fernando Marchesano and Angel Uranga for very useful discussions. I also thank the organisers of the Corfu 2005 Summer Institute for the invitation to present this contribution. The author's work is supported by the University of Cambridge.

References

- [1] S. Kachru, R. Kallosh, A. Linde, J. Maldacena, L. McAllister and S. P. Trivedi, JCAP **0310** (2003) 013
- [2] A. Sen, JHEP **9910**, 008 (1999)
- [3] M. R. Garousi, Nucl. Phys. B **584** (2000) 284 P. Kraus and F. Larsen, Phys. Rev. D **63** (2001) 106004. T. Takayanagi, S. Terashima and T. Uesugi, JHEP **0103** (2001) 019.
- [4] A. Sen, JHEP **0207**, 065 (2002)
- [5] N. Lambert, H. Liu and J. Maldacena, arXiv:hep-th/0303139.
- [6] A. Sen, Int. J. Mod. Phys. A **20** (2005) 5513
- [7] A. Sen, Mod. Phys. Lett. A **19**, 841 (2004)
- [8] P. Mukhopadhyay and A. Sen, JHEP **0211**, 047 (2002)
- [9] A. Sen, Phys. Scripta **T117** (2005) 70
- [10] G. W. Gibbons, Class. Quant. Grav. **20**, S321 (2003), D. A. Steer and F. Vernizzi, Phys. Rev. D **70** (2004) 043527, J. Raeymaekers, JHEP **0410**, 057 (2004)
- [11] D. Cremades, F. Quevedo and A. Sinha, JHEP **0510**, 106 (2005)
- [12] G. W. Gibbons, K. Hori and P. Yi, Nucl. Phys. B **596** (2001) 136
- [13] A. D. Linde, Phys. Lett. B **327**, 208 (1994), A. D. Linde and D. A. Linde, Phys. Rev. D **50**, 2456 (1994), A. Vilenkin, Phys. Rev. Lett. **72**, 3137 (1994).
- [14] I. R. Klebanov and M. J. Strassler, JHEP **0008** (2000) 052
- [15] S. Kachru, S. Katz, A. E. Lawrence and J. McGreevy, Phys. Rev. D **62**, 126005 (2000)
- [16] P. G. Camara, A. Font and L. E. Ibanez, JHEP **0509**, 013 (2005)
- [17] A. Sen, Phys. Rev. D **68** (2003) 106003
- [18] N. Barnaby, C. P. Burgess and J. M. Cline, JCAP **0504**, 007 (2005)
- [19] L. Kofman and A. Linde, JHEP **0207**, 004 (2002)